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Theory and Experiments on Four-Color Beam Smoothing with Spectral Dispersion at the Third Harmonic Wavelength of the Nova Laser*

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Abstract

We report on the theory and experimental development of wide-band (0.15% total bandwidth) four-color target irradiance smoothing with spectral dispersion at the third harmonic wavelength of the Nova laser at LLNL, and implementation of novel bandwidth sources and efficient frequency converter design.

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Theory and Experiments on Four-Color Beam Smoothing with Spectral Dispersion at the Third Harmonic Wavelength of the Nova Laser*

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Summary

Wavefront aberrations in high-power solid-state laser amplifier chains can produce substantial non-uniformities in the target plane irradiance that can degrade the coupling of energy into an ICF target, and drive hydrodynamic instabilities.[1] Local 'hot spots' can induce self-focusing of the light in the laser-driven plasma, producing filamentation that affects the growth rates of parametric instabilities.[2] The adaptation of spatial and temporal incoherence techniques to target irradiance smoothing[3] has received much current interest.[4] The method of smoothing-by-spectral dispersion (SSD)[5] is quite effective at the third harmonic wavelength (3ω), and can substantially reduce irradiance fluctuations over short integration times (1 ~ 30 ps) depending on the overall spectral width.

At Lawrence Livermore National Laboratory, the SSD technique has been extensively developed at second and third harmonic wavelengths,[6] and used for numerous target experiments.[7] The next generation ICF facility, the proposed National Ignition Facility (NIF)[8] has been designed so that groups of four-beamlines will be overlapped to form f/8 beam cones, and spatially shaped on target with kinoform phase-plates.[9] Each beamline will amplify one of four primary frequencies or 'colors', separated by 5 to 10 cm^{-1} at 1ω, and the beams will be frequency converted in wavelength specific phase-matched pairs of doubling and tripling crystals. With an overall bandwidth at 3ω of 45 to 90 cm^{-1} we will achieve rapid intensity smoothing on target. If necessary, frequency modulated (FM) bandwidth at 3ω of up to 6 cm^{-1} (180 GHz), and spectral dispersion (SSD) can be added to each beamline to improve smoothing for longer (30 ~ 300 ps) intervals.

The smoothing rate, $-(1/\sigma)d\sigma/dt$, and the time-integrated variance of intensity or 'smoothness' $\sigma/\langle I\rangle$, for SSD are dependent on the spectral dispersion and bandwidth that a high power amplifier chain can support. The beam divergence that can be tolerated by a laser chain, the reduced conversion efficiency from increased phase-mismatch with bandwidth, and the potential increase in spatial self-

focusing are performance limiting factors. By restricting the FM bandwidth per beamline, we can improve the conversion efficiency and control the beam quality. By separating 'colors' among the beamlines we can also achieve large overall bandwidth. Simulations indicate that optimal utilization of the spectrum is achieved at a dispersion where the speckle field of each spectral component is shifted at the target plane by one-half speckle diameter, $d_{1/2} = 1.22\lambda/D$, where D is the diameter of each beamline, and λ is 351-nm. Each FM spectral component can then add incoherently over a time of one FM period thereby narrowing the integrated probability distribution. The peak rate, $-(1/\sigma)d\sigma/dt$ occurs in a time that is the inverse of the overall bandwidth, and is linearly proportional to the number of overlapping beamlines. Theory shows that the rate of four-color smoothing with SSD is ~4 times higher than one-color smoothing at the same f-number per beamline, reaching a lower asymptotic $\sigma/\langle I \rangle$ by ~ 2 times, because of the ~ 4 times larger spectral width.

Recently, we implemented a four-color SSD smoothing scheme on Nova,[10] with capabilities similar to that described for NIF. One Nova beamline was divided into four equal-area, 26 x 26 cm^2 quadrants, each with a distinct primary 'color', and independently frequency tripled with a newly developed four-quadrant, wavelength-tunable array - using type I / type II phase-matched pairs of KDP crystals. The four colors were generated in the Nova laser oscillator facility by nonlinear mixing of two laser pulses in a single-mode polarization-preserving optical fiber, with frequencies separated by 4 cm^{-1}, spaced equally relative to the Nd:YLF laser line at 1053 nm. The four colors were spatially separated at the input to the Nova pre-amplifier chain, spatially-apodized and spectrally-dispersed, using a novel four-quadrant grating multi-chrometer. The measured equivalent target irradiance showed 25 ~ 50% rms smoothness with the four narrowband colors, and our simulations indicate that we reached this in ~3-ps. With the addition of FM bandwidth to all quadrants, we measured 10 ~ 20% rms smoothness with an overall spectral width of 1.3 THz (0.15%) at 3ω. Simulations indicate that this rms smoothness is substantially achieved in less than 30-ps. We delivered 1.5 to 2.3 kJ of light on target with 600-ps to 1-ns square pulses from the four energy-balanced quadrants, corresponding to an efficiency at the crystal array of >65%. For target experiments, LLNL random-phase-plates (RPPs)[11] were used with 5.8-mm and 9.0-mm square element sizes to obtain target irradiances between 2×10^{15} and 5×10^{15} W/cm^2 at the center of a 350 ~ 550 µm diameter spot. Extensive target experiments were performed with this system to examine parametric instabilities with four-color beam smoothing, and showed a noticeable reduction of back-scattered SBS from hydrocarbon filled gas-ballon targets.[12]

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